

Undergraduate Research Thesis:

The effects of compression tights on biomechanics related to overuse
running injuries

Undergraduate Student:

Samuel M. Seelbach

Principal Investigator:

Dr. Ajit Chaudhari, PhD

Research Mentor:

Margaret E. Raabe

Study Sponsor:

Nike, Inc.

Table of Contents

List of Figures	(ii)
List of Tables	(iii)
Abstract	(iv)
Introduction	(1-5)
Methods	(6-16)
Results & Discussion	(17-23)
Acknowledgements	(24)
References	(25-26)

List of Figures

Figure 1:	Full-Length Compression Tights Worn by Participants	(9)
Figure 2:	Protocol for Sessions 2-4 with Vibration Run Circled	(10)
Figure 3:	Series of Four Force Plates	(11)
Figure 4:	Laser Gate at End of Force Plates	(12)
Figure 5:	Marker Labeling System	(13)
Figure 6:	Full Marker Set in Nexus	(14)
Figure 7:	Runner in Stance Phase on Force Plate	(15)
Figure 8:	Effects of Compression Tights on Injury-Related Biomechanical Angles	(19)
Figure 9:	Effects of Compression Tights on Injury-Related Biomechanical Moments	(19)
Figure 10:	Effect of Compression Tights on Vertical Impact Peak	(20)

List of Tables

Table 1: Effects of Compression Tights on Injury-Related Biomechanical Variables	(18)
--	------

Abstract

With about half of the nearly 15 million runners being injured annually and no current methods stemming the tide, there is a need to find effective treatments. These injuries are most commonly from overuse. Compression tights have been advertised to enhance performance and address injuries by improving biomechanics. In the past, small changes in biomechanical variables have been associated with runner injuries. Due to the cyclical loading of running, these small biomechanical changes can accumulate into the overuse injuries so prevalent in the sport. Compression garments have not had their effect on many injury-related biomechanical variables analyzed yet. We proposed to use running biomechanics data from another study to determine the effect of compression tights on biomechanics related to runner injuries. Each participant ran across force plates at a speed ($\pm 5\%$) corresponding to 80% of their max VO_2 . By comparing the conditions of no compression to high compression (20-25 mmHg) with paired t-tests, no significant results were detected. Vertical impact peak was trending upward ($p < 0.1$) with high compression, which implies that the tights may be increasing the risk for developing Tibial Stress Fractures. There appeared to be no significant beneficial or detrimental effects from high compression tights on overuse injury-related biomechanical variables for the 10 runners used in this study. This study could be repeated to control for preferred running distance, and identify a target population size with a power analysis. Outside of running biomechanics, there still may be an effect on muscle exhaustion, psychology, proprioception, or EMG patterns from compression garments. It remains an important endeavor to find effective methods to reduce the rate of runner injuries by investigating other injury prevention strategies.

Introduction

Running is one of the most popular modes of exercise in the United States, and continues to grow in popularity. The sport is widely accessible with a low cost and provides many health benefits. In 2014, there were 10,687,500 female and 8,062,500 male finishers reported for running events. The number of people who completed a running road race increased by 22% from 2012 to 2013.¹ Many of these runners wear compression garments during training and racing. Compression garments are advertised by brands such as Skins and CW-X to improve biomechanics.^{2,3} Many believe these claims and frequently use them to enhance their running performance, or to address injury concerns. Of course, another possibility is that runners simply purchase compression garments for aesthetic or warmth purposes and any other possible benefits are a bonus.

About 50% of runners get injured annually – typically via overuse.⁴ Due to the cyclical loading of running on the lower extremities, an accumulation of tissue microdamage can outpace the healing mechanisms of the body and cause an overuse injury.⁵ Many methods have been attempted to reduce the rate of injuries in runners including: altering training, using stretching or warm-up techniques, applying shoes and orthotics, buying into the barefoot/minimalist mindset, manipulating biomechanics with other approaches, changing diet, or employing psychological strategies.⁴ Despite the use of one or a combination of these methods, the rate of injuries has not declined significantly. Compression garments may present another biomechanical strategy to reduce injuries that will be further investigated in this paper.

Existing scientific evidence supporting claims made by sports companies about the effectiveness of compression tights has been contradictory. While compression tights have a strong perceptual following, their advertised biomechanical benefits have yet to be proven.

Doan et al. found when testing 20 competitive track athletes wearing compression shorts that their counter movement jump height was increased when compared with controls.⁶ On the other hand, Kraemer et al. found that wearing compression shorts did not significantly affect jump performance for male and female varsity volleyball players.⁷ Kemmler et al. found running performance, measured as time until exhaustion, was significantly increased in moderately trained male athletes when wearing below knee compressive stockings.⁸ However, other studies have found that compression garments offer no effect on running performance. Faulkner et al. studied 11 male runners wearing a variety of lower-limb compression garments (shorts, sleeves, tights) and found no change in 400 meter performance.⁹ Similarly, Doan et al. found compression shorts had no effect on 60 meter sprint time for track athletes.⁶ These studies have given contradictory results due to their varied populations, types of compression garments, and how performance was measured. Few have investigated the use of full length compression tights, where the compressive condition is applied to the entire area of the leg. In addition, most studies try to relate wearing compression garments to performance rather than to injuries. Lastly, in the relatively small number of studies on compression garments, not many have examined their effects on biomechanics. Thus, we propose to determine the effects of full length compression tights on biomechanical variables associated with common running injuries.

Three common overuse running injuries include: Patellofemoral Pain Syndrome (PFP), Iliotibial Band Syndrome (ITBS), and Tibial Stress Fractures (TSF). Beginning with PFP, it is felt as pain around or behind the patella during activities loading the patellofemoral joint. PFP accounts for about 25% of all identified knee injuries.⁴ Proper patellar sliding, or tracking, in the patellar groove of the femur depends on many factors such as the quadriceps tendon force, patellar tendon force, and lateral knee forces. This complex joint can develop PFP from a variety

of sources, so our understanding of its development is limited.⁴ Continuing with ITBS, this injury is felt as pain where the iliotibial band crosses over the lateral femoral condyle and is the second most common cause of knee pain. The iliotibial band is thought to be under the most tension at 30° of knee flexion. Repeated motion around this angle could be a risk factor for developing ITBS, and runners approach 30° during early stance phase at each step.⁴ Lastly, TSF is a small crack in the tibia that can be painful and potentially lead to a larger bone breakage. Since these injuries are primarily from overuse, it is important to discuss how small biomechanical changes can make a big difference for this type of injury. Hoeger estimated that a male 8min/mile runner takes 1,360 steps per mile.¹⁰ The most common racing distance is a 5k comprising 45% of all running event finishers in 2015.¹¹ Ogles, with a population of 482 male runners calculated an average of 37.09 miles per week of training for a 5k, 9.23 years of training for 5ks, and 6.37 5ks completed previously.¹² Below in Equation 1 is a quick calculation showing how many steps are taken per year by this hypothetical runner:

$$1360 \left(\frac{\text{steps}}{\text{mile}} \right) * \left(37.09 \frac{\text{miles}}{\text{week}} * 52 \frac{\text{weeks}}{\text{year}} * 9.23 \text{ years} \right) + \left(3.1 \frac{\text{miles}}{5k} * 6.37 \text{ 5k's} \right) = 24 \times 10^6 \text{ steps or } 2.7 \times 10^6 \frac{\text{steps}}{\text{year}}$$

Equation 1

Thus, about 2.7 million steps are taken per year for these hypothetical runners. This rough estimate gives an idea of how a runner's joints are loaded over and over. The loading of lower extremities is thought to be the primary cause of overuse injuries.⁵ A small biomechanical benefit for each step could snowball into a larger benefit of injury mitigation.

Biomechanical variables have been studied extensively as mechanisms for injury and as potential targets for injury prevention. For example, increased GRF has been linked with a higher likelihood of developing a tibial stress fracture in runners.¹³ Increased step frequency has been found by Schubert et al to decrease ground reaction force.¹⁴ This does not necessarily

connect step frequency to tibial stress fractures, but it implies a possible relationship that warrants investigation. To study the interaction of a biomechanical variable with an injury requires a long expensive study that tracks many athletes over time. Shorter studies, such as Schubert's above and this one, explore if different variables are worth studying in more detail for those longer and more expensive studies. Continuing with an injury mechanism example, a study by Varela-Sanz et al. found that step frequency did not change from compression tights.¹⁵ Stickford et al. also observed that peak ground reaction forces did not change from compression tights.¹⁶ The tights appear to not influence step frequency, a variable associated with the ground reaction force, which is related to tibial stress fractures. The tights also do not affect the ground reaction force, but this does not mean that tights do not contribute to tibial stress fractures. The tights simply do not appear to affect the aforementioned variables that have been associated with the injury. Tights may still alter different biomechanical variables, might affect tibial stress fractures through a non-biomechanical pathway, or they may do nothing at all. Many of the other kinematic and kinetic variables associated with running injuries have not been extensively examined with compression tights. PFP has had higher peak values, taken over the stance phase, of knee abduction angle¹⁷, hip internal rotation angle¹⁸, knee adduction impulse & moment¹⁹, and knee flexion moment²⁰ associated as risk factors. Similarly, ITBS has had hip adduction moment & impulse²¹, trunk ipsilateral angle, hip adduction angle²², and knee internal rotation angle²² associated with its development. Lastly, TSF has had vertical impact peak²³, vertical loading rate²³, and knee adduction impulse²⁴ linked to its risk of development. This warrants further research to determine the potential effects of compression tights on these injury-related biomechanical variables.

The purpose of this study, using a subset of existing data, was to determine the effect of compression tights on running mechanics associated with common running injuries. I hypothesized that compression tights will beneficially lower peak biomechanical variables associated with common running injuries including knee abduction angle, hip internal rotation angle, knee adduction impulse & moment, external knee flexion moment, hip adduction moment & impulse, trunk ipsilateral angle, hip adduction angle, knee internal rotation angle, knee adduction impulse, vertical impact peak, and vertical loading rate. Knowledge gained from this study will provide insight into the potential of compression tights to reduce biomechanical variables associated with injury risk for runners.

Methods:

This study used data provided by another study, done by Ajit Chaudhari et al., that was funded by Nike with the primary goals of looking at how compression affects muscle exhaustion, muscle vibration, and soreness. Simultaneously, biomechanical data was collected during running, and that data was used for this study. All methods were shared by both studies, but not all the methods were relevant to each study. The Ohio State institutional review board approved all methods. A sample size of 20 healthy male runners was recruited using flyers and social media. All participants were filtered with an online enrollment questionnaire with the following inclusion/exclusion criteria:

Inclusion:

- Male
- Over 18 years old and under 30 years old at time of testing
- Comfortable running a 10k
- Self-reports a natural heel strike running pattern
- Regularly run at least 30 minutes 3 times per week

Exclusion:

- Female
- Have experienced any running injury (diagnosed by self or medical professional) over the past 3 months
- BMI greater than 30
- Self-reports a midfoot or forefoot strike running pattern
- A history of recurrent low back pain

Male runners were exclusively recruited, due to typically having less body fat in the hips and thighs than women²⁵, so that any observed lower-limb vibration would be primarily due to muscles. Participant BMI was also limited to ensure that skin vibration was primarily due to muscles rather than other soft tissues. The age was limited to 18-30 due to the effects of sarcopenia where muscles atrophy with age. These effects appear to begin by the age of 40, if not sooner.²⁶ Thus, to ensure maximum muscle mass, the age range did not encompass sarcopenia-prone participants. Running pattern was limited to a heel strike to make the ground reaction forces as similar as possible between subjects. This way, the muscle vibration could be more easily compared between subjects. To get experienced runners that could realistically run for 30 minutes at a fast speed, the criteria of being comfortable running a 10k and running 30 minutes 3 times per week were included. In order to make sure subjects were all relatively healthy to eliminate any effects of injuries, low back pain history and recent running injuries were excluded.

Qualified participants came in for four visits to the Sport Biomechanics Laboratory at the Martha Morehouse Medical Plaza. The first session familiarized each participant with the tests, and had measurements such as height, weight, and other anthropometric data recorded. Importantly for this study, participants performed a graded treadmill test in session 1 to estimate their VO_2 max during running. VO_2 max is an estimate of an athlete's maximum volume of oxygen that they can use, and is the current best estimate of an athlete's aerobic fitness. After any warm up each participant wanted to do, the treadmill test started with an easy jog (2.5 m/s) for 5 minutes to acclimate the participant to the treadmill. Then, the treadmill speed was increased by 0.3 m/s every 2 minutes. The test continued until the participant felt they could not

go any longer. The maximum speed reached during the test was used to estimate VO_2 max using Equation 2 shown below, where S is speed and G is grade:

$$\text{VO}_2 \left(\frac{\text{mL}}{\text{kg} \cdot \text{min}} \right) = 0.2 * S \left(\frac{\text{m}}{\text{min}} \right) + 0.9 * S \left(\frac{\text{m}}{\text{min}} \right) * G + 3.5 \quad \text{Equation 2}^{27}$$

Equation 2 is composed of three components: horizontal, vertical, and rest oxygen cost. The horizontal oxygen consumption coefficient of 0.2 ml/(kg*m) represents moving 1 kilogram 1 meter horizontally and is double the coefficient in the walking equation. Thus, the oxygen demand for running is roughly twice as much as for walking horizontally. Since the vertical work is partially done through the horizontal movement, the coefficient of 0.9 ml/(kg*m) is about half compared to the vertical component in the walking equation. Lastly, the resting cost of oxygen is constant for running and walking at 3.5 ml/(kg*min). This equation is valid for speeds over 5 mph, which all participants exceeded during running for this study.²⁷ A chest harness was worn for safety throughout all treadmill testing, and research staff were available to act in case of an emergency.

The content presented in this paragraph is not relevant for looking at biomechanical variables, but displays the methods used by the larger study. The next three sessions had a randomized condition of no tights, low compression tights (10-15mmHg), or high compression tights (20-25mmHg). All tights were provided by Nike, Inc and an example of one is shown in Figure 1 below. Black patterns with additional material are adhered on the thigh and calf portions of the tights that apply extra compression to those areas where much of the lower-limb muscle mass is present. Similar compressive patterns are seen in other brands of compressive garments as well.

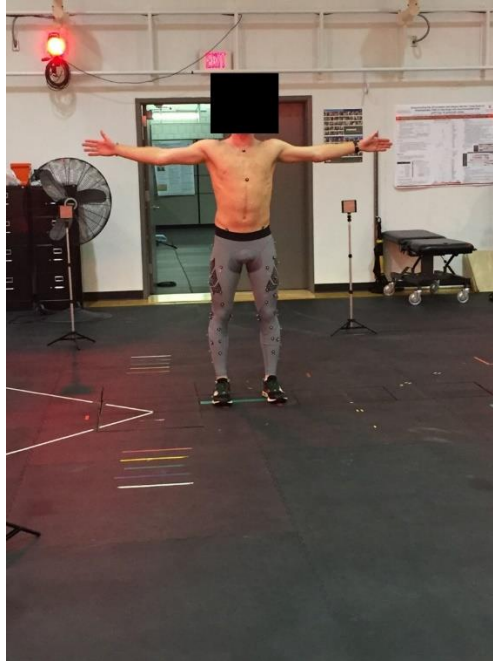


Figure 1: Full-Length Compressive Tights Worn by Participants

At the sessions with low and high compression tights, a PicoPress® was used to measure pressure underneath the compression tights. A PicoPress® inflates small plastic balloons taped to the skin underneath compressive garments, which then, via a manometer mechanism, measures the pressure (MediGroup EDI, Melbourne AU). The subjects completed a soreness survey after sessions, and an exercise diary at the start of each session. Intuitively, the soreness survey was to see how sore the participants felt after each session and assess the effects of compression tights on soreness. The exercise diaries were simply a way to look at the self-reported training of each subject and ensure it was fairly consistent. The general procedure of the three condition sessions is shown in Figure 2 below:

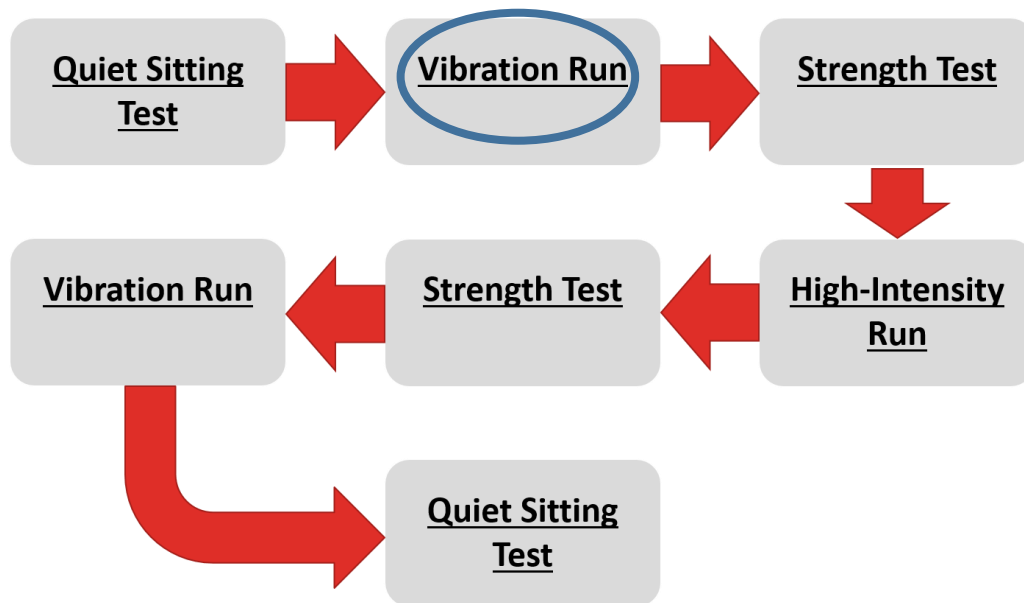


Figure 2: Protocol for Sessions 2-4 with Vibration Run Circled

There was a quiet sitting test, vibration run, and isometric strength test before and after a high-intensity run to look at muscle exhausting effects on the aforementioned variables. The quiet sitting tests were an assessment of core stability, the vibration runs were an assessment of muscle vibration, and the isometric strength tests were an assessment of muscle strength. For this study, only data from the vibration run circled in Figure 2 before the high-intensity run was used to eliminate exhaustion as a factor.

For the vibration run, each subject had reflective markers placed on key anatomical locations to record kinematics. Nine Vicon Cameras (MX-F40, Vicon, Oxford UK), mounted in a semicircle formation around the force plate volume, were used. Participants were then instructed to run across a series of four Bertec 4060-10 force plates (Bertec, Worthington OH) at 80% of the speed used to calculate their VO_2 max. Figure 3 below shows the force plates embedded into the floor. Force plates 4 and 6 were not used for this study because participants ran in a straight line across force plates 1,2,3,5.

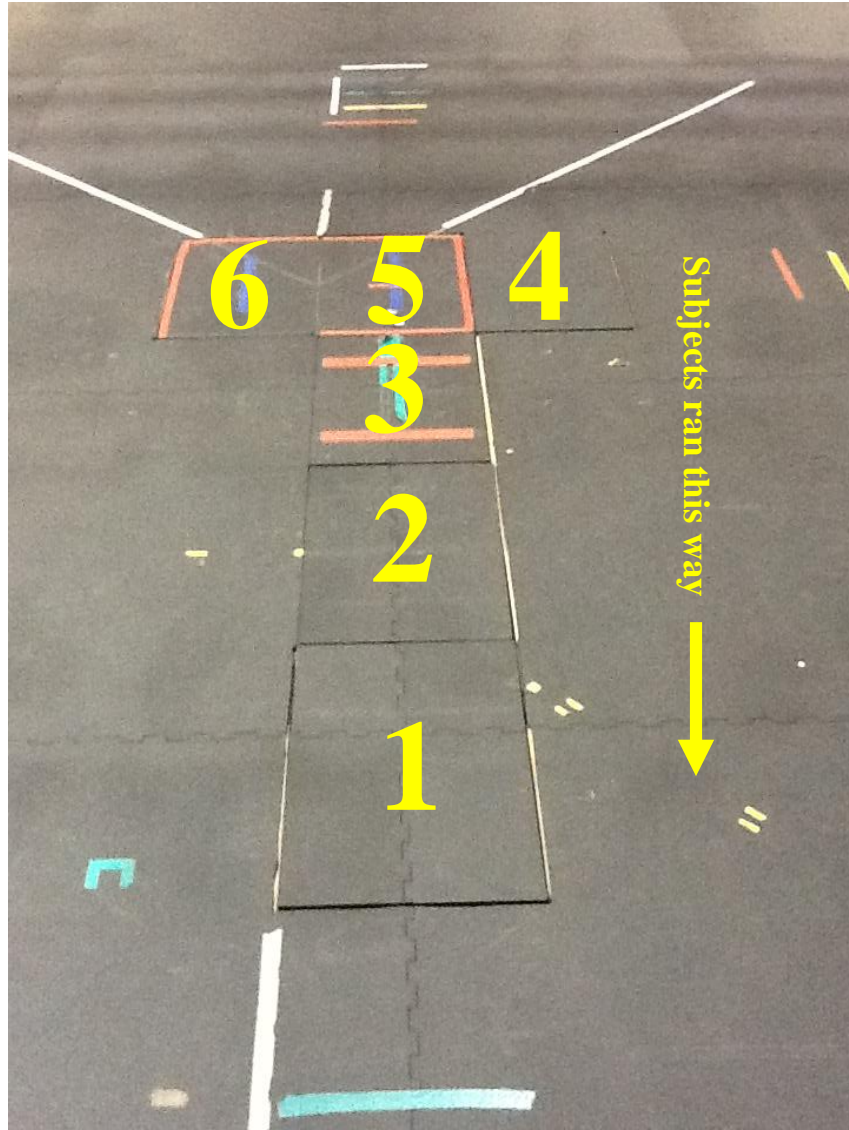


Figure 3: Series of Four Force Plates

Speed was captured using SMARTSPEED PT laser gates (Fusion Sport, Brisbane AU) with the lasers positioned at the start and end of the four force plates. These laser gates are shown setup in Figure 4 below:

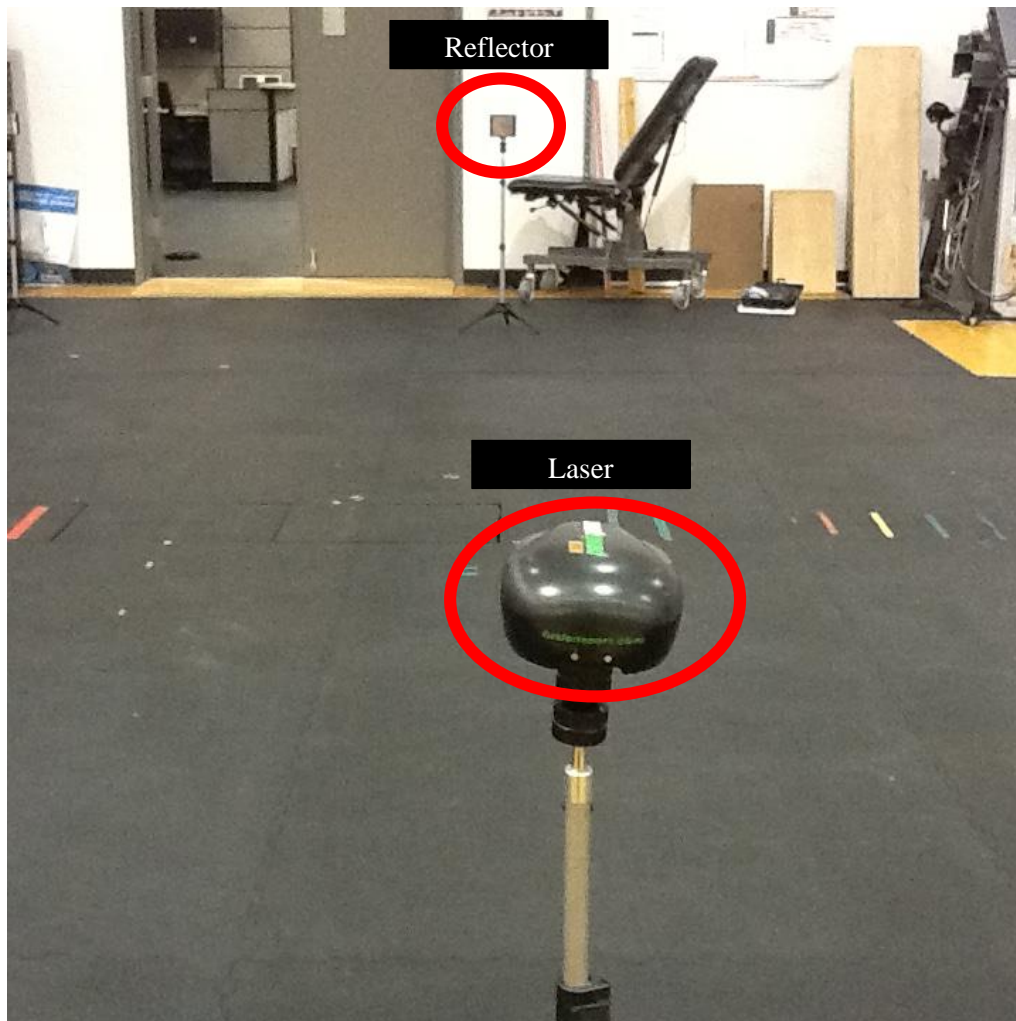


Figure 4: Laser Gate at End of Force Plates

If the subject was not maintaining the speed pertaining to $80\% \text{ of max VO}_2 \pm 5\%$, then the trial was not recorded. Five trials were recorded for this test per condition. Nexus Motion Capture Software (Vicon, Oxford UK) was used to record 3D kinematics with a point cluster method. Motion capture with inverse dynamics has been validated over the past 30 years as a method to determine motion and forces acting on the body.²⁸

In the Nexus Software, the clustered marker set shown in Figure 5 was used:

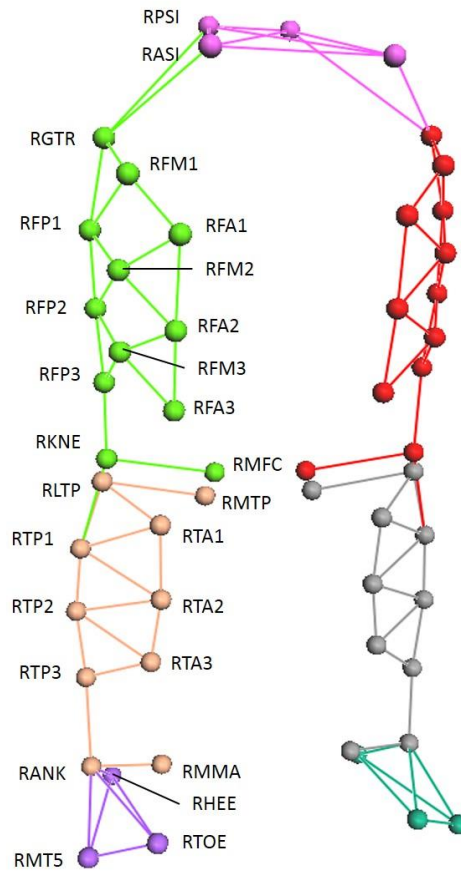


Figure 5: Marker Labeling System

The left leg is identical to the names used for the right with an L in front instead. Each marker pertained to an anatomical landmark for a joint or segment of the lower-limb. Upper-body markers that are not shown here were also used to add a trunk segment to assess the trunk bending angle. Figure 6 shows the full point cluster marker set used, although there were additional vibration markers as well that did not pertain to this study. Each is color coded in Figure 6 as well.

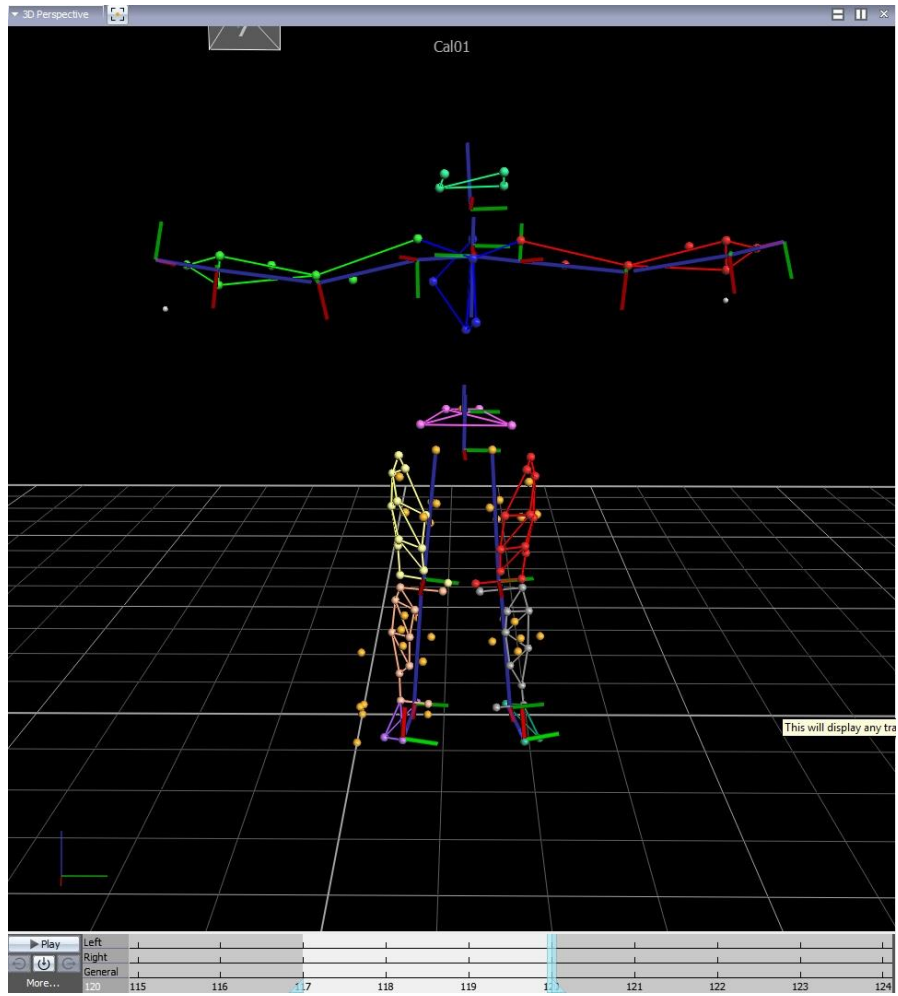


Figure 6: Full Marker Set in Nexus

An example image of a runner during stance phase on the force plates is shown in Figure 7. The darker orange dots do not represent actual markers.

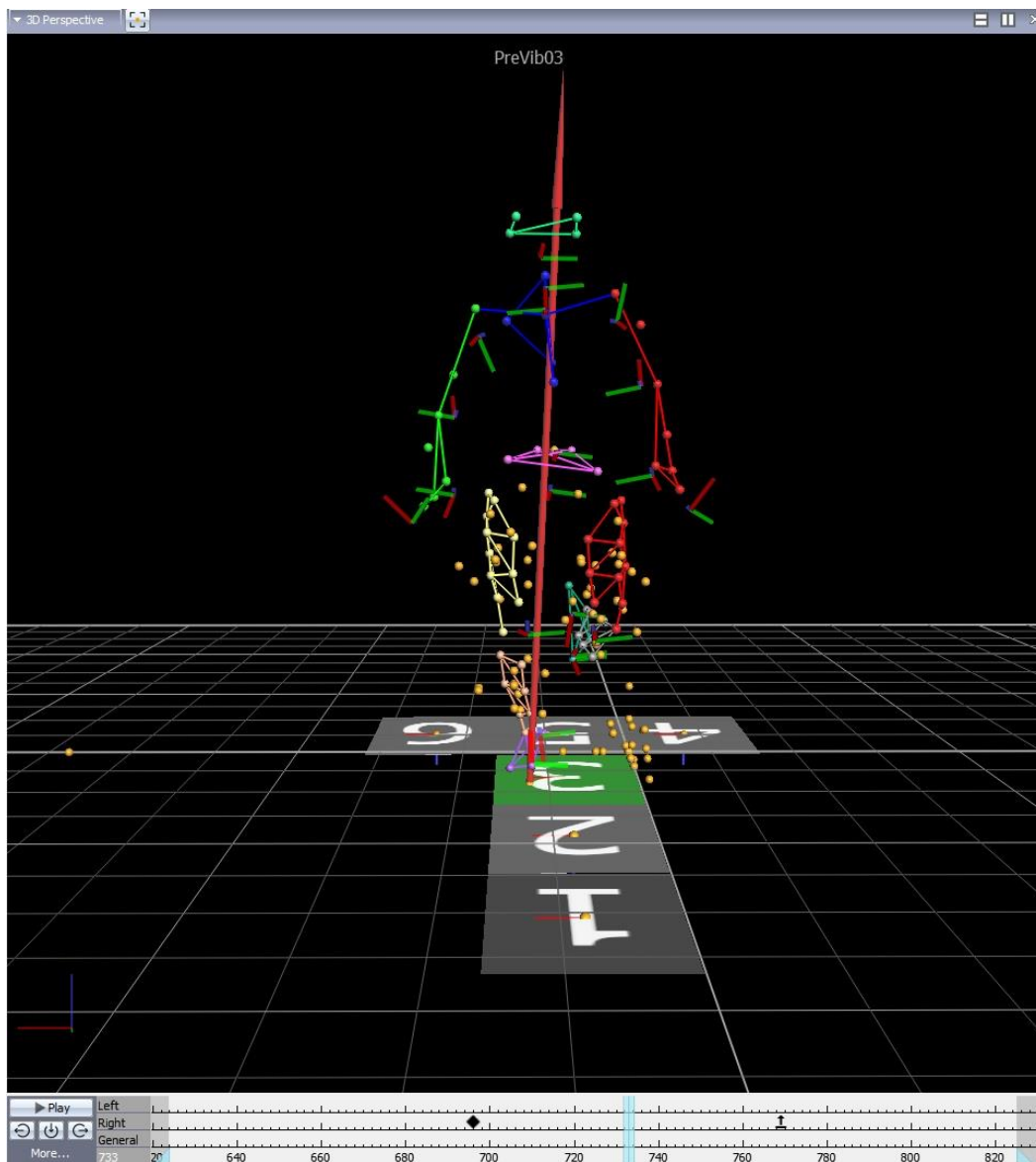


Figure 7: Runner in Stance Phase on Force Plate

A set of exclusion criteria were used to remove some of the vibration run data. All low compression conditions were eliminated so that only the no compression condition would be compared to the high compression condition. Only subjects with data present for both the no compression and high compression conditions were included. If vital reflective markers for

kinematics and kinetics calculations were missing, the trial was not used. If a session had less than two usable trials, the session was not used – and thus the opposing condition session was also not used. This way, an equal number of no compression and high compression sessions could be averaged. Leg dominance was not controlled for in either study. If available, the data of the self-reported dominant leg was used. Otherwise, the non-dominant leg was assumed to be equivalently affected by the compression tights and used instead.

No compression was compared to high compression. All trials within a single session were averaged. Then, the opposing conditions of each subject were compared so that each subject served as their own control. Nexus Motion Capture Software and MATLAB (Mathworks, Natick MA) were used to perform inverse dynamics, filter and calculate variables of interest. Matlab scripts used were written and modified by Ajit Chaudhari, Mike McNally, Scott Monfort, and Margaret Raabe from the OSU Sports Biomechanics Research Laboratory. Notably, the marker trajectories of the motion data were filtered with a Butterworth low-pass filter at 15Hz. The force data was not filtered at all. MATLAB was also used to perform statistics. Microsoft Excel (2015) was used to plot the data of interest. A paired t-test, using each subject as their own control, was used to compare the selected biomechanical variable trial averages of no compression to high compression. A trending value was defined as $\alpha < 0.1$, and a significant value was defined as $\alpha < 0.05$. Due to the exploratory nature of this study, no corrections for multiple comparisons were performed.

Results & Discussion:

A total of 10 runners were identified as usable with the exclusion criteria. None of the running injury-related biomechanical variables were significantly different with the application of high compression tights. All forces and moments were normalized to body weight, and moments were also normalized by subject height. Normalizing by body weight was to make participants of different sizes more comparable to each other. Likewise, normalizing the moments by height was to account for the fact that taller individuals have longer lever-arms contributing to the moments in their limbs due to having longer limbs. For example, the units listed for impact peak are N/BW, or percent body weight, because the vertical force in newtons was divided by the subject's body weight. Furthermore, all moments and impulses were normalized to both body weight and height. Thus, $BW \cdot h$ appears in their denominators and cancels the units of N and mm in the numerator giving percent body weight times height. All variables in each condition with their standard deviations and p-values are shown in Table 1:

Table 1: Effects of Compression Tights on Injury-Related Biomechanical Variables

Units	Biomechanical Variable	No Compression			High Compression			p-value
Angle (°)	Hip Adduction Angle	11.02	±	3.74	11.64	±	4.35	0.58
	Hip Internal Rotation Angle	5.11	±	5.49	5.03	±	11.05	0.97
	Trunk Ipsilateral Angle	9.53	±	3.39	13.84	±	12.27	0.35
	Knee Abduction Angle	4.44	±	3.00	5.14	±	4.47	0.59
	Knee Internal Rotation Angle	10.31	±	5.21	10.92	±	8.57	0.76
N*mm/(BW*h)	Knee Flexion Moment	1.26	±	0.21	1.22	±	0.33	0.57
	Hip Adduction Moment	1.16	±	0.29	1.19	±	0.44	0.78
	Knee Adduction Moment	0.75	±	0.20	0.70	±	0.18	0.39
N*msec*mm/(BW*h)	Knee Adduction/Abduction Impulse	79.33	±	29.36	69.70	±	22.54	0.18
	Hip Adduction/Abduction Impulse	123.86	±	22.54	122.00	±	34.12	0.84
N/BW	Vertical Impact Peak	1.92	±	0.49	2.10	±	0.51	0.07
N/(BW*s)	Vertical Loading Rate	11.73	±	4.88	11.04	±	7.36	0.61

A subset of the results in Table 1 are also displayed visually in Figures 8-10 below. Several representative angles and moments were plotted in Figures 8 and 9 respectively to visually show the lack of significant difference between conditions. The vertical impact peak was also plotted in Figure 10 since it had an upward trending p-value to visually show that the difference is very small. If this trending is correct, it implies that the impact peak is increased from the use of compression tights. An increase in impact peak has been linked with an increased risk of developing a tibial stress fracture.²³

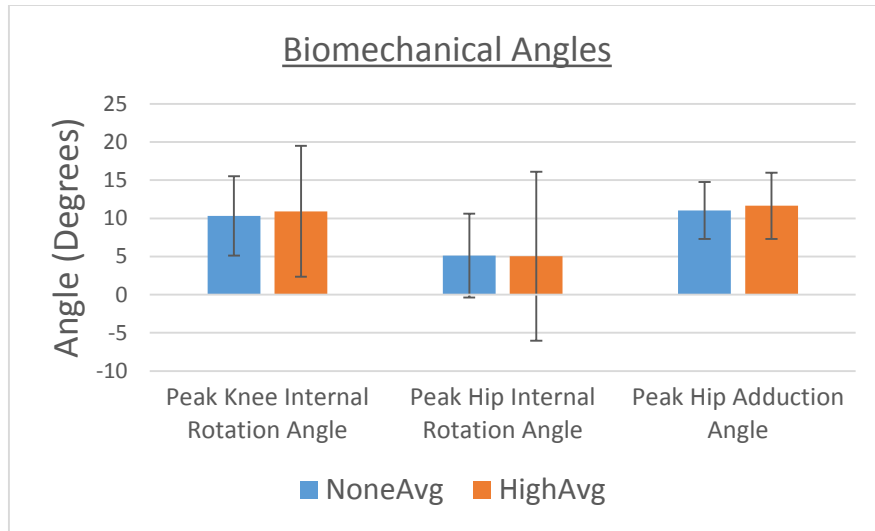


Figure 8: Effects of Compression Tights on Injury-Related Biomechanical Angles

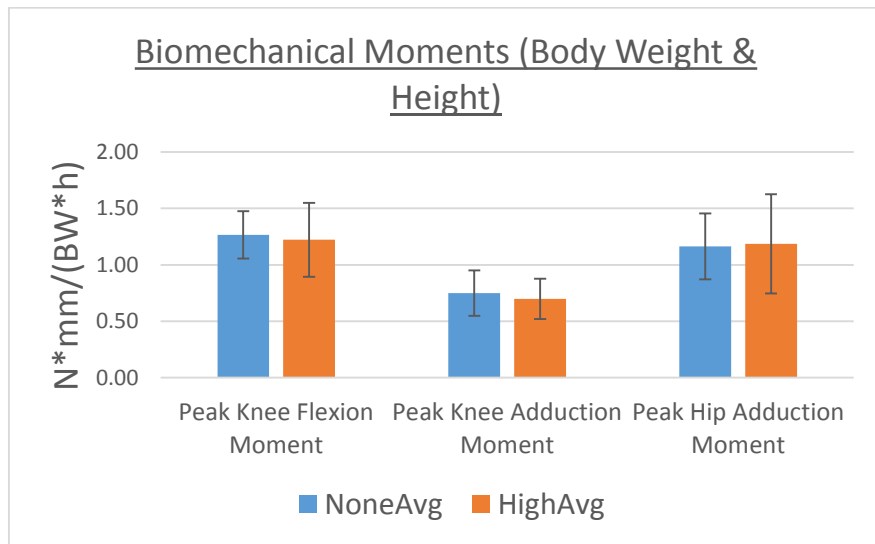


Figure 9: Effects of Compression Tights on Injury-Related Biomechanical Moments

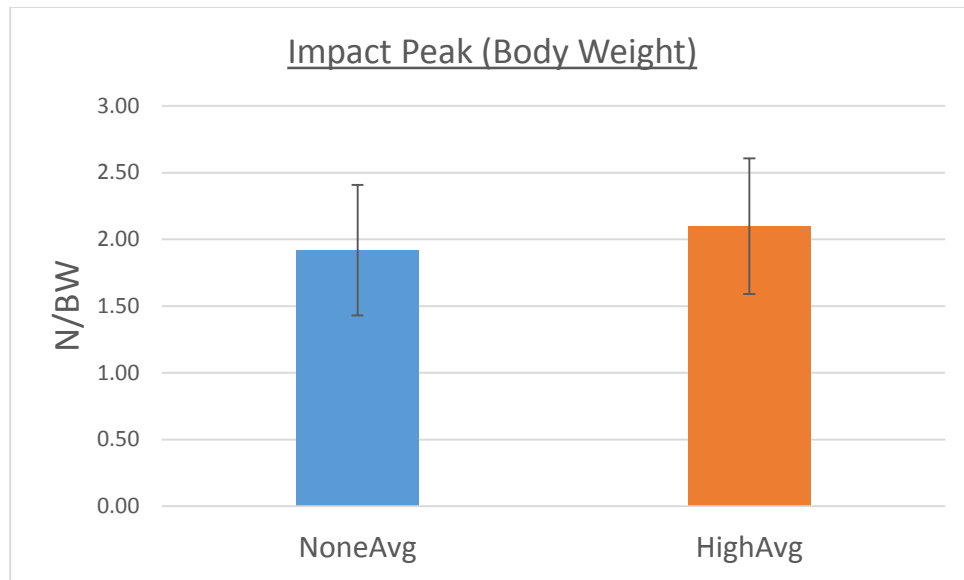


Figure 10: Effect of Compression Tights on Vertical Impact Peak

There appears to be no significant reduction or increase in any of the biomechanical variables associated with common runner injuries, in these 10 runners. A small trend towards an increase in vertical impact peak, a variable linked to tibial stress fracture risk, was seen from the use of high compression tights. Full-length high compression tights may not provide a benefit towards preventing runner injuries via altering biomechanical variables. Interestingly, a related study by Lucas et al. found that compressive stockings reduced peak tibial acceleration compared with controls in 40 runners who underwent 3 weeks of training with compression stockings.²⁹ If this were true for the population in this study, a decrease in tibial acceleration should also reduce the force applied. In opposition to this expected trend, the impact peak increased slightly from the use of compression tights in this population. The reasons for this apparent disagreement may be from a difference in methods. Lucas et al. collected kinematic data over a much longer interval, but they did not record any forces and could not calculate kinetic variables. The inclusion criteria were very similar between both studies, but Lucas et al. also excluded anyone that had

used compression garments in the past. This may have been done to remove any possible enduring learning effects caused by previous use of compression.

The limitations of this study begin with considering that it was a branch of a larger study. If recording injury-related biomechanical variables was the sole goal, the methods may have differed by using self-pacing, recruiting more subjects, and improving the efficiency of biomechanical data capture during running. The running speed was chosen based on a high-intensity run. An inherent issue with this type of test is that people may stop before they are truly exhausted to end the test. In addition, running speed differed depending on each subject's fitness level and preferred running distance which ranged from a casual 5k runner to an experienced marathoner. Perhaps an upper limit in running ability should have been used. In contrast to a set-speed calculated from Equation 2, self-pacing may have been a better alternative to more realistically mimic training or race conditions rather than using an established set speed.³⁰ Furthermore, a novel self-pacing VO₂ max test was also shown to typically give higher values than a standard graded exercise test.³¹ This calls into question which testing method gives a more accurate measurement of VO₂ max. Continuing, with only 10 subjects, the variability from fitness levels and other factors may have been too great to see any significant effects. Significant effects with more subjects could be too small a difference to be clinically relevant, but it still may be worth investigating. Only 10 out of the 20 subjects were able to have their biomechanics evaluated during running. This was in part due to important reflective markers falling off during the running trials. Many trials did not have biomechanical data from the dominant leg, so in these cases the non-dominant biomechanical data was used instead if available. The population was relatively healthy and the compression should affect both legs similarly, so there was likely only a small amount of variability introduced from varying which

leg was used in each trial. Several trials had no force data due to the participants not being instructed to run across the force plates. These trials were originally intended to collect muscle vibration data for the larger study, so force data and many marker trajectories were not required to be collected. More subjects could have been used if the data was consistently ensured to have all force and motion data collected.

In the future, this study could be repeated for a larger population with their preferred running distance controlled for and with a self-pacing protocol. Or, the effect of compression tights on different set running speeds could be analyzed as well. Biomechanics, intuitively, changes dramatically at different speeds.³² Compression tights may have larger effects at certain speeds pertaining to specific running events rather than all of them since it was not controlled for in this study. In addition, the psychological and proprioceptive effects of compression tights could be further investigated. Thus far, compression garments have not had significant perceptual effects, such as perceived exertion, on runners.³³ Sensorimotor function, relating to proprioception, is an important factor in postural control that has not been studied much in runners. Poor postural control can contribute to altered loading responses in runners, possibly leading to injuries.³⁴ Compression garments have been shown to improve the proprioception of the knee regardless of leg dominance.³⁵ However, a biomechanical benefit from compression garments was not seen in this study regardless of whether or not it stemmed from a proprioceptive mechanism. A last interesting approach could be developing a smart-material compressive garment that allows electromyography (EMG) measurement without disrupting compression in the measured areas. Only external forces and moments can be calculated with inverse dynamics from force plate and motion data. The only method to realistically look at the internal forces provided by muscles is by studying their electrical activity through skin voltage

changes via EMG measurements. Unfortunately, current EMG sensors placed under compression garments would bulge the material and may alter how the garment is affecting that particular area. EMG has been shown to change in runners from the use of orthotics, another injury prevention strategy.³⁶ The effects of compression garments on EMG for runners has not been investigated as of yet, but novel approaches to measuring EMG underneath compression must be developed first.

High-Compression tights were worn by experienced male runners during running. The tights did not appear to significantly alter peak stance biomechanics associated with overuse injuries in the sport. Further investigation of injury-prevention strategies is still needed in order to find suitable methods to stem the tide of nearly half of runners being injured each year.

Acknowledgement of Funding:

This project was funded by and for Nike, Inc.

References

- 1 *Statistics and Running*, <<http://www.runningusa.org/statistics>> (2016).
- 2 *How It Works - CW-X*, <https://www.skins.net/ch_en/skins-science/> (2016).
- 3 *SKINS Science*, <https://www.skins.net/ch_en/skins-science/> (2016).
- 4 Callahan, L. R. & Sheon, R. *Overview of running injuries of the lower extremity*, (2013).
- 5 Hreljac, A. Impact and overuse injuries in runners. *Medicine and science in sports and exercise* **36**, 845-849 (2004).
- 6 Doan, B. *et al.* Evaluation of a lower-body compression garment. *Journal of sports sciences* **21**, 601-610 (2003).
- 7 Kraemer, W. J. *et al.* Influence of Compression Garments on Vertical Jump Performance in NCAA Division I Volleyball Players. *The Journal of Strength & Conditioning Research* **10**, 180-183 (1996).
- 8 Kemmler, W. *et al.* Effect of compression stockings on running performance in men runners. *The Journal of Strength & Conditioning Research* **23**, 101-105 (2009).
- 9 Faulkner, J. A., Gleadon, D., McLaren, J. & Jakeman, J. R. Effect of lower-limb compression clothing on 400-m sprint performance. *The Journal of Strength & Conditioning Research* **27**, 669-676 (2013).
- 10 Hoeger, W. W., Bond, L., Ransdell, L., Shimon, J. M. & Merugu, S. One-mile step count at walking and running speeds. *ACSM's Health & Fitness Journal* **12**, 14-19 (2008).
- 11 *Statistics and Research*, (2016).
- 12 Ogles, M. B., Masters, S. K. & Richardson, A. S. Obligatory Running and Gender: An Analysis of Participative Motives and Training Habits. *International Journal of Sport Psychology* **26**, 233-248 (1995).
- 13 Davis, I., Milner, C. E. & Hamill, J. Does increased loading during running lead to tibial stress fractures? A prospective study. *Med Sci Sports Exerc* **36**, S58 (2004).
- 14 Schubert, A. G., Kempf, J. & Heiderscheit, B. C. Influence of Stride Frequency and Length on Running Mechanics A Systematic Review. *Sports Health: A Multidisciplinary Approach*, 1941738113508544 (2013).
- 15 Varela-Sanz, A., España, J., Carr, N., Boullosa, D. A. & Esteve-Lanao, J. Effects of gradual-elastic compression stockings on running economy, kinematics, and performance in runners. *The Journal of Strength & Conditioning Research* **25**, 2902-2910 (2011).
- 16 Stickford, A. S. L., Chapman, R. F., Johnston, J. D. & Stager, J. M. Lower-Leg Compression, Running Mechanics, and Economy in Trained Distance Runners. *International journal of sports physiology and performance* **10**, 76-83 (2015).
- 17 Chen, Y.-J. *et al.* Comparison of three-dimensional patellofemoral joint reaction forces in persons with and without patellofemoral pain. *J Appl Biomech* **30**, 493-500 (2014).
- 18 Powers, C. M. The influence of altered lower-extremity kinematics on patellofemoral joint dysfunction: a theoretical perspective. *Journal of Orthopaedic & Sports Physical Therapy* **33**, 639-646 (2003).
- 19 Stefanyshyn, D. J., Stergiou, P., Lun, V. M., Meeuwisse, W. H. & Worobets, J. T. Knee angular impulse as a predictor of patellofemoral pain in runners. *The American journal of sports medicine* **34**, 1844-1851 (2006).
- 20 Andriacchi, T., Kramer, G. & Landon, G. in *American Academy of Orthopaedic Surgeons, Symposium on Sport Medicine. The Knee*. Finerman, G., ed., St. Louis, Mosby. 23-32.
- 21 MacMahon, J. M., Chaudhari, A. M. & Andriacchi, T. P. in *ISBS-Conference Proceedings Archive*.
- 22 Aderem, J. & Louw, Q. A. Biomechanical risk factors associated with iliotibial band syndrome in runners: a systematic review. *BMC musculoskeletal disorders* **16**, 1 (2015).

- 23 Davis, I. S., Bowser, B. J. & Mullineaux, D. R. Reduced vertical impact loading in female runners with medically diagnosed injuries: a prospective investigation. *British journal of sports medicine*, bjsports-2015-094579 (2015).
- 24 James, S. L. Running injuries to the knee. *Journal of the American Academy of Orthopaedic Surgeons* **3**, 309-318 (1995).
- 25 Karastergiou, K., Smith, S. R., Greenberg, A. S. & Fried, S. K. Sex differences in human adipose tissues—the biology of pear shape. *Biology of sex differences* **3**, 1 (2012).
- 26 Metter, E. J., Conwit, R., Tobin, J. & Fozard, J. L. Age-associated loss of power and strength in the upper extremities in women and men. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* **52**, B267-B276 (1997).
- 27 Baumgartner, T. A. & Jackson, A. S. *Measurement for evaluation in physical education and exercise science*. (WCB/McGraw-Hill, 1998).
- 28 Andriacchi, T. P., Alexander, E. J., Toney, M. K., Dyrby, C. & Sum, J. A point cluster method for in vivo motion analysis: applied to a study of knee kinematics. *Journal of biomechanical engineering* **120**, 743-749 (1998).
- 29 Lucas-Cuevas, A. *et al.* Effect of 3 Weeks Use of Compression Garments on Stride and Impact Shock during a Fatiguing Run. *International journal of sports medicine* **94**, 826-831 (2015).
- 30 Sloot, L., Van der Krogt, M. & Harlaar, J. Self-paced versus fixed speed treadmill walking. *Gait & posture* **39**, 478-484 (2014).
- 31 Mauger, A. R., Metcalfe, A. J., Taylor, L. & Castle, P. C. The efficacy of the self-paced V O₂max test to measure maximal oxygen uptake in treadmill running. *Applied Physiology, Nutrition, and Metabolism* **38**, 1211-1216 (2013).
- 32 Mann, R. A. & Hagy, J. Biomechanics of walking, running, and sprinting. *The American journal of sports medicine* **8**, 345-350 (1980).
- 33 MacRae, M. B. A., Cotter, J. D. & Laing, R. M. Compression garments and exercise. *Sports medicine* **41**, 815-843 (2011).
- 34 Switlick, T., Kernozek, T. W. & Meardon, S. Differences in joint-position sense and vibratory threshold in runners with and without a history of overuse injury. *J Sport Rehabil* **24** (2015).
- 35 Ghai, S., Driller, M. W. & Masters, R. S. The influence of below-knee compression garments on knee-joint proprioception. *Gait & Posture* (2016).
- 36 Nawoczenski, D. A. & Ludewig, P. M. Electromyographic effects of foot orthotics on selected lower extremity muscles during running. *Archives of physical medicine and rehabilitation* **80**, 540-544 (1999).